

# **Advanced Development of PipeGuard™**

**(Public Version)**

**Proactive Pipeline Damage Prevention**

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**Final Project Report**

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## **PART I**

### **1. EXECUTIVE SUMMARY**

PipeGuard™ was designed to detect digging and other potentially hazardous activities in close proximity to buried pipelines. Unauthorized third party digging in the vicinity of buried gas transmission and distribution lines poses a real threat to this vital part of the nation's infrastructure and to the greater public safety. An initial study was conducted to ascertain if the technology embodied in PipeGuard™ was applicable for the protection of gas pipelines. The results of the initial study were positive, but indicated some additional work was required to improve detection sensitivity and accommodate high ambient noise levels. The effort documented in this report was to develop an advanced adaptation of PipeGuard™ to effectively detect these digging events and notify the appropriate response areas or personnel. A primary objective to detect backhoe digging within 250 feet of a Sensor Unit in 2 minutes or less was established. The results of this effort should be of interest to all gas companies that own and operate buried natural gas pipelines in areas where third party digging is a potential threat.

The original PipeGuard™ (PG) Sensor Unit (SU) employed geophones to convert ground pressure waves produced by surface and sub-surface activity into electrical impulses, and signal processing electronics to analyze the electrical signal for indications of digging. The initial step of the Advanced PG Development effort was to conduct digging tests with various tools and equipment to establish the baseline performance of the original design and determine specifically where improvements were needed. The design and implementation of the geophones was found to be adequate. The signal processing hardware and analysis software required improvement. The signal processing electronics were redesigned incorporating higher performance components to provide a more precise representation of the signals produced by the geophones over a wider magnitude range. The system would now be able to differentiate faint impulses caused by digging activity from the background noise produced by all other activity occurring in the vicinity of the sensing units. Prototypes of the new design electronics were built and used to record signal patterns of various tools and equipment such as backhoes, pneumatic piercing (missiles) tools and pavement breakers. Providing a clearer picture of the signals produced during these types of events and background activity, the results were used to develop a series of algorithms to analyze the signal for those characteristics relating to below ground surface activity. Finally, the improved electronics and software were combined with a new enclosure designed to minimize installation and purchase costs and assure the performance and reliability of the Advanced PipeGuard System.

Advanced PG Sensor Units were installed at two test sites, one at the original location in Stony Brook, NY and a new location in Mt. Pleasant, NY. The characteristics of the two sites differ to provide a broader evaluation of system performance. At each location a series of

digging tests was conducted using various mechanical and manual digging implements at various distances from the SU's. The time to alarm was recorded for each trial. Detection performance was found to be significantly improved compared to the original design, but did not meet the simultaneous goals of detecting backhoe digging at 250 feet in 2 minutes or less. The goals were met separately, however, and proved the PipeGuard™ technology is effective for detecting digging events in environments with and without significant background noise.

## **2. BACKGROUND**

Third party digging poses a substantial risk to the nation's buried gas pipelines. Mechanized digging equipment can easily cause catastrophic damage resulting in major outages with potential personal injury and loss of life and property damage. Even incidental contact from hand or mechanized digging tools can damage pipe surfaces or protective coatings resulting in accelerated local deterioration and requiring eventual repair. Some measures have already been implemented to mitigate the risk of third party digging. Placing markers on the surface above pipelines and establishing and promoting "Call before you dig" programs can help reduce accidental pipeline damage. These measures, however, depend only on the diligence of the third party digger to be effective. A more direct approach to reducing pipeline damage from unauthorized digging events is to actually detect the digging activity and alert the appropriate agencies.

There are several factors that complicate the task of detecting digging activity reliably and with few nuisance alarms. First, existing pipeline is generally inaccessible for easy installation of direct mounted sensors. Trenching for the installation of a cable based sensor running parallel to the pipeline may be prohibitively expensive. Another complicating factor is the areas where the likelihood of third party digging is greatest often have high levels of other activity. These may be areas adjacent to busy roadways and commercial centers where background noise levels are high, but the frequency of construction projects involving digging is also high. Another factor is the variety of digging equipment that may be employed. It ranges from hand tools like digging bars and shovels, to larger mechanized shovels and backhoes, to pneumatic missiles and jack hammers. Finally the local soil conditions dictate how much noise is produced when digging, and how well the sound propagates through the soil. For this application, any successful system must contend with these factors.

In March, 2008 NYSEARCH and Senstar Inc. embarked on a research and development project entitled "Third Party Excavation Detection for Damage Prevention". The focus of the project was to determine if Senstar's PipeGuard™ product could detect digging activity near buried pipelines. The PipeGuard™ system utilizes battery powered Sensing Units located along the pipeline. A compact array of geophones is buried about three feet deep in close proximity to

each Sensing Unit. Alarm data from each Sensing Unit is transmitted wirelessly to a Base Station from which the information is relayed to the command and control center.

The selection of a test site for the PG units was an important consideration. As a participating member of NYSEARCH, National Grid offered a site in Stony Brook, NY that met the testing criteria. The site is on Long Island at the intersection of Nesconset Highway and Nicolls Road. Both are major roadways of six lanes (plus left and right turn lanes) carrying high volumes of traffic. The site offers open working space adjacent to the roadways where excavation equipment can be deployed without disrupting traffic flow. Vehicles of all classification from automobiles to heavy trucks travel in large numbers through this intersection creating a very dynamic environment for a seismic sensor. Two PipeGuard<sup>TM</sup> SU's were installed at the intersection; one at the southeast corner and the other approximately 460 feet away north along east Nicolls Road. The communications base station was installed in a large enclosure on a utility pole on the northeast corner along with a video encoder, network switch and a Raven cellular modem. Higher on the same pole a fixed video camera was mounted and focused on the area around the SU at the southeast corner.

The initial test was conducted in December 2008. At this time no communication link had been established to National Grid's Hicksville office. Therefore, the alarm output of the SU's was monitored locally at the site with the Base Station connected directly to a Notebook PC running the Fortis<sup>TM</sup> application. PipeGuard<sup>TM</sup> test results are shown in *Table 1*.

## Test # 1 –Results

Equipment	Detection Distance (ft)	Detection Time	Comments
Backhoe	75, 100 & 130	1 min to 2.3 min	
Mini-Backhoe	65, 75, 140, 185	2.2 min to 3.25 min	At 185' two tests could hear at 2 <sup>nd</sup> unit - not enough to detect
Small Missile	75	1.3 min	Two tests - missile travel less than 5 feet
Pavement Breaker	80	40 sec	<b>Two tests - grass area &amp; pavement with tamper pad</b>
Shovel	30, 50, 53	2.3 min to 3.3 min	No detection at 100 feet

**Table 1: PipeGuard™ Test #1 Results**

The results of this initial test were very encouraging. They showed the ability to detect manual excavations along with various mechanized excavations with no nuisance alarms being recorded.

A second excavation test was conducted in November 2009 (see results in *Table 2*). Prior to this test a PC running the Fortis™ application was installed at National Grid's Hicksville office so alarm activity could be monitored remotely. Also a video camera was focused on the SEC of the site was installed so that the operator can view any alarm event detected at this location. The SEC was selected because this area seemed to generate a significant amount of third party activity.

Test	Unit	Distance (ft)	Direction	Equipment	Time Start	Time Finish	Detection Level
1	1	60	East	Shovel	9:51:00	9:56:50	No Detection
2	1	60	East	Backhoe	9:57:25	10:00:50	No Detection
3	1	60	East	Back Fill	10:04:25	10:05:45	High Confidence
4	1	30	East	Shovel	10:11:25	10:19:50	No Detection
5	1	30	East	Backhoe	10:20:37	10:22:30	Low Confidence
5a	1	30	East	Backhoe		10:22:44	Medium Confidence
6	1	30	East	Back Fill	10:25:50	10:28:41	Basic Confidence

7	1	60	SW	Pave Breaker	10:35:45	10:36:11	High Confidence
8	1	60	SW	Backhoe	10:38:45	10:40:44	Basic Confidence
8a	1	60	SW	Backhoe	10:50:00	10:56:44	Basic Confidence
9	1	60	SW	Missile	11:06:56	11:07:25	Excellent Confidence
10	1	150	SW	Pave Breaker	11:19:55	11:19:58	Basic Confidence
10a	1	150	SW	Pave Breaker		11:20:23	High Confidence
11	1	150	SW	Pave Breaker	11:27:40	11:29:45	Excellent Confidence
12	1	150	SW	Backhoe	11:53:00	11:59:05	No Detection
13	1	150	SW	Missile	12:02:15	12:04:10	Medium Confidence
14	1	200	SW	Breaker-Soil	13:39:34	13:41:27	High Confidence
15	1	200	SW	Backhoe	13:45:55	13:48:17	Low Confidence
16	1	200	SW	Breaker-Asph	13:56:10	13:59:54	Low Confidence
17	4	100	N	Breaker-Asph	14:33:16	14:33:50	High Confidence
18	4	100	N	Breaker-Soil	14:38:07	14:39:13	Excellent Confidence
19	4	100	N	Breaker-Asph	14:43:22	14:44:36	Excellent Confidence
20	4	100	N	Backhoe	14:49:39	14:55:26	No Detection
21	4	100	N	Breaker-Soil	14:59:15	15:01:42	Medium Confidence
22	4	200	N	Breaker-Asph	15:16:25	15:17:38	Excellent Confidence
23	4	200	N	Breaker-Soil	15:20:52	15:22:34	High Confidence
24	4	260	N	Breaker-Soil	15:26:35	15:27;28	Basic Confidence
25	4	65	N	Backhoe	15:38:55	15:44:53	Medium Confidence

**Table 2: PipeGuard™ Test #2 – Results from November 2009**

The results from the 2009 test were less successful. Some digging scenarios that had been detected in the previous test were not detected. These tests illustrated that more development work was required to investigate system variables such as geophone placement and sensor gain. It was also discovered that, although not strictly a part of the PipeGuard™ product, the communication link between the base station at the site and the Fortis™ application at a remote company facility needed to be improved. These and other related issues were to be investigated in the Phase II effort.

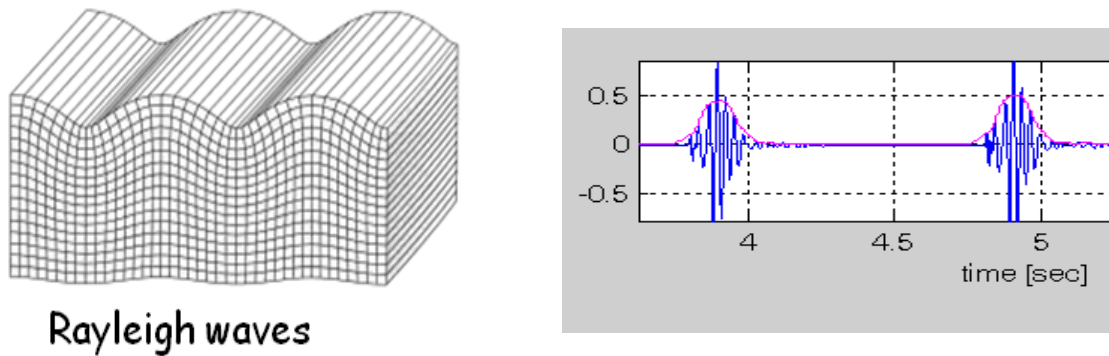
In December 2010, NYSEARCH and MSI agreed to conduct the Advanced Development of PipeGuard™ project. The general objective of the project was to further develop the PipeGuard™ product to better suit the specific requirements of this application. The project work scope was established to progress from the existing system to identify and implement specific improvements; conduct extended operational tests; and generate a comprehensive economic analysis.

### 3. TECHNOLOGY DESCRIPTION

The overall design objectives for the PG system were to provide a high level of sensor performance along with application flexibility and simple installation all at reasonable cost. The PG is designed to be a flexible sensor system that can easily be deployed in various configurations. It uses a modular approach where each sensor unit is independent and self-contained, yet functions as part of a group. From 1 to 32 sensor units can report through one base station and an unlimited number of base stations can report to a Fortis™ control and command unit.

Following this modular approach, sensor units include all of the electronics to gather, and process information to make an alarm determination, then distribute this information throughout the system. The process starts with pressure waves produced by digging events and other surface and sub-surface activity.

Surface activity (e.g., digging) generates compression waves (known as Rayleigh Waves) which are detected by the geophone and converted to voltage pulses that are relayed to the SU PCB.



**Figure 1: Rayleigh Waves**

The pressure waves travel through the ground just as sound travels through air. Geophones are used to convert these pressure waves to analog electrical impulses. The geophones consist of a cylindrical moving wire coil suspended by springs that surrounds a fixed magnet. The entire assembly is housed in a rugged, sealed case. The housing and the fixed magnet vibrate as pressure waves travel by. Meanwhile the coil maintains its position due to inertia. The relative motion between the coil and magnet generates an electrical signal that faithfully represents both the frequency and magnitude of the pressure waves. Each geophone is connected via a direct-burial cable to the Sensing Unit (SU). Geophone transducers are a

rugged, well established technology and have been used for many years in the fields of seismic studies and oil exploration. Each Sensor Unit utilizes four geophones arranged in an array to better characterize the pressure waves.

The determination if an alarm condition exists due to a digging event is accomplished within the digital signal processing (DSP) board that is housed in the SU. The functions of the DSP board include amplifying the signals produced by the geophones to usable levels, converting the analog signals to a digital representation for processing, and conducting the actual signal processing as orchestrated by software instructions. Most of these functions are handled by a single, highly integrated microcontroller. The microcontroller combines many functions including analog to digital conversion, signal processing, memory, and timers on one chip. Along with other operating instructions, the software loaded to the microcontroller also includes the alarm algorithms. These are the specific rules used to determine if the signals received from the geophones represent an actual digging event or are environmental.

Power for the SU is provided by a lithium battery pack. This adds to the flexibility of the overall design by eliminating any need for external power supplies or connections. The battery pack is designed to have a service life of approximately 5 years, but actual life is a function of the activity level at the specific installation site. The SU electronics are designed to draw very little power when seismic activity is low, by entering a hibernation state. In general, when seismic activity levels increase, so does processing activity and power consumption. The SU is designed to operate from other power sources as well according to the application.

When an alarm event occurs or on command from the base station the SU will transmit the required information. Transmission is by way of a spread-spectrum, frequency hopping and a mesh network. The outdoor, line of sight (LOS) transmission range is approximately 800 meters. The mesh network provides communication to the base station by sending information from one SU to the other. For example a Sensing Unit installed more than 800 meters away from or not within LOS of a base station will still have full communication with the base station by relaying messages through SU's at intermediate locations. Also, since the maximum transmission range is more than twice the typical 500 feet (157 meters) separation distance between SU's, a single failed SU will not disrupt communication from other units located down range.

The base station is the two-way communication node that is capable of serving up to thirty two (32) Sensing Units. It ensures all Sending Units are operating normally by regularly polling each unit and commanding a response. The base station is also linked to the Fortis<sup>TM</sup> Command and Control system and routes commands from the Fortis<sup>TM</sup> to the SU's as well as relaying alarm information. Each base station is configured with an IP address and requires (12) Volts of DC power.

A reliable communication link must exist between the base station and Fortis<sup>TM</sup> system, typically located remote from the site. One option is provide a cell modem located in close proximity to the base station and connected via an Ethernet cable. Another option is to connect via an Ethernet link to the Fortis<sup>TM</sup> Command Center. Cell modem units provide a direct gateway to the internet by way of a third party cellular network, and are configured with static IP addresses. Along with conveying alarm system data from the base station to the Fortis<sup>TM</sup> Command Center, cell modems can also carry digital video signals from installation sites to a remote workstation. They are particularly well suited for this application because they require; no other infrastructure other than a DC power source and they are commonly used by utility operators as part of their SCADA systems. Other options for linking the base station(s) to the Command units are copper or fiber based WAN (Wide area Network), satellite modems, or private microwave or licensed radio links.

Fortis<sup>TM</sup> is an integrated command and control system designed to provide operators with timely alarm information from remote sensors along with capabilities to present video, relay information to mobile users, and log system activity. The Fortis<sup>TM</sup> Command and Control Center is the operator control interface for the PG system. It is a comprehensive Windows based security control application. The display provides the Graphic User Interface (GUI) for the operator. An overhead view of the protected area is presented to the operator. When an alarm is activated the red alarm indicator appears on the screen and an audible alert tone is generated. The operator selects the alarm details window and additional information regarding the alarm is available including the “confidence level” in addition to controls to Confirm (Acknowledge) and Delete (Reset) alarms. Fortis<sup>TM</sup> can be configured to send alarm notification messages to others via e-mail, text or voice messages. An event log file is available showing an historical record of alarm activity. Finally, if the video option is used, Fortis<sup>TM</sup> can display remote video from the PG location.

#### **4. TECHNOLOGY DEVELOPMENT**

A design objective to provide backhoe detection at (250) feet range, within 2 minutes, and a nuisance alarm rate of less than 1% was initially established by natural gas companies funding the project. Comparing these objectives with actual results from digging tests conducted in December 2010 and April 2011, it was evident that a substantial overall increase to performance was required. The test site at Stony Brook, NY exhibited a very challenging set of characteristics for detecting excavating events. The soil being a sandy-loam mix (soft soil) creates less ground movement during an excavating event and background noise from the nearby heavy vehicle traffic is excessive. This generally requires additional signal analysis other than just comparing signal amplitudes to differentiate digging events from environmental activity. From a signal processing perspective MSI's goal was to acquire a relevant signal, ensure its quality, and extract the pertinent information needed to make an accurate alarm determination. The challenge is to improve performance in these respects while keeping power usage and costs as low as possible. As a result, both hardware and software changes were needed.

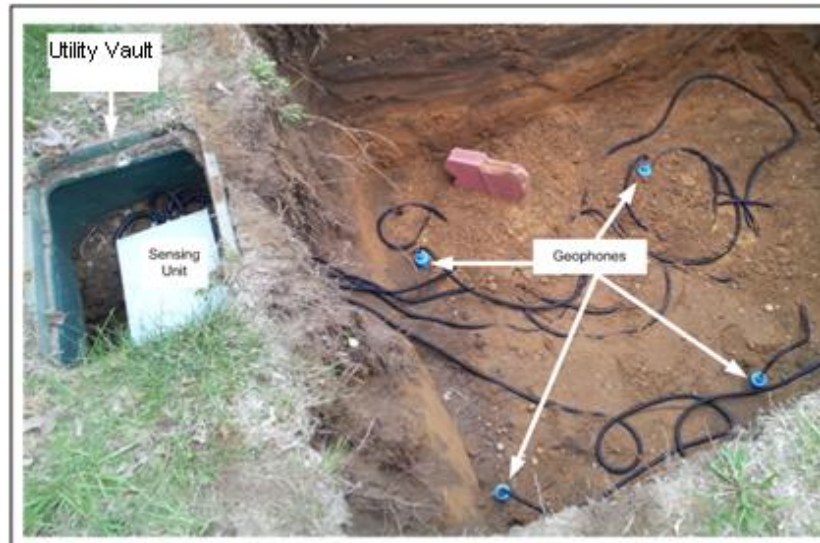
#### **5. APG INSTALLATION – TWO TEST SITES**

The characteristics of the test sites have a large influence on the performance of the systems. The soil composition affects the signals received by the Advanced PG units in two ways. First, the strength of the original signal is influenced by the interaction of the digging equipment/tools with the soil. Steel digging tools impacting rock or hard clay produce distinctive sharp pulses whereas soft, sandy soils present very little resistance and hence a more reduced signal impulse. Soil composition also affects how the impulses are transmitted from the dig location to the geophones. At times, buried objects like large rocks and tree roots can impede the transmission of impulses by attenuating the signal or reflecting it away from the sensors. As mentioned previously, excessive background noise level is also major determinant to system performance. Regardless of soil conditions, the signals produced by any digging event will be more distinct and easier to detect if background noise levels are relatively low. The test site selected must offer convenient access for digging equipment and sufficient area to allow evaluation of multiple excavations at distances up to (250) feet from Sensor Units.

The initial NYSEARCH test site at Stony Brook, NY was retained as one of two sites for this development effort. It is at the intersection of two heavily traveled roadways and has sandy type soil conditions throughout the site. The open area available is somewhat limited, but sufficient to conduct the required digging tests. Overall, the Stony Brook site is very challenging due to the high level of background noise and its soil conditions. The Sensor Units are located approximately 460 feet apart on opposite sides of Nesconset Highway. The Base Station enclosure was mounted to an existing utility pole between the two Sensor Units. The line-of-sight (L-O-S) distance from Sensor Units to the base station does not exceed 300 feet.

Consolidated Edison of New York (Con Edison) volunteered to host the second APG site. Several sites were evaluated in the Bronx/Westchester NY area. A grassy area at the Con Edison's Eastview Maintenance Facility was selected. This site located in Mt. Pleasant, NY offers a good combination of environmental features for the test location and is different, in many ways, than the Stony Brook site. It is relatively private with no public access to the property. The test area is within the perimeter fence of the maintenance facility. There is a busy highway (Saw Mill Parkway) running parallel and outside the test area about 100 feet northwest of the site. Immediately adjacent to the test area is a utility access roadway and parking area. During the early morning and mid -afternoon hours there is a significant amount of car and truck traffic at the site, otherwise traffic is considered to be light. Based on this, the Eastview site sees more variations/fluctuations of background noise, than Stony Brook. There is also more variation in soil characteristics. Eastview has soils with high clay content with pockets of stone/rock. At the Eastview site, Sensor Unit #2 is located (500) feet Northeast of Sensor Unit#1 and the Base Station enclosure is mounted to an existing utility pole located about 50 feet northeast of SU#2.

Advanced PG Sensor Units were installed at the Eastview facility on May 9, 2012. Two Sensor Units were installed about (500) feet apart. To install each sensor unit a 48" X 48" by 40" deep excavation was made. Adjacent to the excavation a small plastic utility box was installed to provide easy access to the Sensor Unit enclosure. The geophones were embedded in undisturbed soil at the bottom of the excavation in a square configuration with each side approximately 28 inches, and the diagonals measuring 40 inches, as shown in *Figure 2*.



**Figure 2: Geophone Installation**

Once in position, the geophones and their respective cables were covered with a layer of soil and tamped into place. The excavation was backfilled with soil compacted to assure that proper contact between the geophones and surrounding soil. The antenna lead was routed from the SU in the utility box and installed in a 48” plastic pipe. The antenna was secured at the top of the pipe using electrical tape. The plastic pipe serves to protect the antenna and antenna lead from mechanical damage as well as providing some elevation to improve the RF communication between the SU’s and the base station, shown in *Figure 3*.



**Figure 3: Antenna Installation**

This same basic installation was used at both the Eastview and Stony Brook test sites. The enclosure contains a “RavenX” cellular modem, a 4-port network switch and plug-in power supplies for each. Antennae for the base station and RavenX are mounted to the top of the enclosure. The Base Station installations differ slightly at the two sites. The Eastview site uses an IP camera mounted to the same utility pole as the Base Station enclosure. The Stony Brook site utilizes an analog video camera that requires a video encoder to digitize the video signal for transmission via the RavenX cell modem. In addition the Stony Brook system includes video recording capability and the enclosure includes the Base Station, RavenX modem, network

switch, video encoder and USB hard drive. At both test sites primary power for all electronics other than the Sensor Units is 115V/60 Hz, see *Figure 4*.



**Figure 4: Typical Base Station Installation**

A Command and Control workstation for the Eastview site was installed at Con Edison's GERC (Gas Emergency Response Center) in Bronx, NY. The workstation consists of a typical Windows® 7 based, desktop PC including keyboard, mouse and LCD monitor, and cellular modem. The control and annunciation functions are provided by Senstar's Fortis™ Command and Control software application.

An APG workstation supporting the Stony Brook test site was installed at National Grid's Hicksville facility. The workstation hardware was the same as that installed at GERC. The Hicksville Fortis™ application though was configured to demonstrate some additional capabilities.

## **6. TEST RESULTS**

The Advanced Pipeguard system was first installed at the Eastview test site the week of May 7, 2012. Digging tests were conducted using the following implements: backhoe; pneumatic missile; and pneumatic pavement breaker with tamper attachment. These implements were chosen for the test because they are readily available and thus most likely to be used by third parties in a digging event. Once SU#1 and SU#2 were installed, they were calibrated with a few initial digging tests with a shovel and backhoe. For calibration, each SU was connected directly via a USB cable to a PC. In this mode, the live signal generated by each geophone can

be viewed and recorded while monitoring the outputs from the algorithms. The parameters for each algorithm were adjusted based on the local environment and confirmed in successive digging tests. After calibration, the SU's were returned to wireless communication mode so the outputs from both could be monitored from the base station. All of the test digging events were conducted by a Con Edison maintenance crew. The crew was directed to dig at a specific location, with a particular type of implement and to continue digging until they were told to stop.



**Figure 5 - Mini-Backhoe (Stony Brook)**



**Figure 6 - Typical Pneumatic Missile**



**Figure 7 - Backhoe and Rocky Soil (Eastview)**



**Figure 8 - Pneumatic Missile Operation**



**Figure 9 - Backhoe Operation (Eastview)**



**Figure 10 - Pavement Breaker  
Operation**

The Sensing Units included four algorithms that operate simultaneously. Algorithm (1) is specifically tailored to detect manual digging. Algorithm (2) detects general digging activity based on the intensity and duration of impulses and is well suited to detect mechanical digging. Algorithm (3), based on the standard deviation of the impulses, continuously compares activity levels over time. Algorithm (4) was designed for detection of low intensity events over relatively long time periods. This algorithm is intended for use in quiet environments and during calibration it was determined that algorithm (4) produced excessive nuisance alarms with the relatively noisy conditions present at both test sites. The SU's at both test sites are configured to use only algorithms (1), (2) and (3). The results from the digging tests are shown below:

<b>Equipment</b>	<b>Distance (Feet)</b>	<b>Direction</b>	<b>Alarm (Yes/No)</b>	<b>Confidence Level/Time to alarm (MM:ss)</b>
Backhoe	250	North	Yes	1/ 4:07
Backhoe	200	North	Yes	1/ 0:50 2/ 1:50
Backhoe	250	South	Yes	1/ 01:40 2/ 02:30 3/ 02:40
Pneumatic Missile	250	North	Yes	1/ 0:40 2/ 0:45 3/ 0:49
Pneumatic Missile	200	North	Yes	1/ 0:25 2/ 0:30 3/ 0:37
Pneumatic Missile	250	South	Yes	1/ 1:26 2/ 2:21 3/ 2:31
Breaker/Tamper	250	North	No	
Breaker/Tamper	200	North	Yes	1/ 0:30 2/ 0:40
Breaker/Tamper	250	South	Yes	1/ 2:23

**Table 3: Test Results, Eastview, May 2012**

The results show major improvement especially in detecting backhoe excavations compared to the results obtained from digging tests conducted at Stony Brook April 6, 2011 prior to the introduction of the Advanced PG hardware or software enhancements.

The original PG Sensor Units at the Stony Brook site were replaced with the new Sensor Units on May 15, 2012. The new units were calibrated using the same process as used at Eastview site. The digging tests at Stony Brook were conducted by National Grid maintenance crews using a mini-backhoe, pneumatic missile and pneumatic pavement breaker with a tamper attachment in paved areas. The tamper attachment was used to prevent damage to the pavement in roadway areas. Again, the results indicate a substantial improvement in backhoe detection compared to the April, 2011 data as shown below in *Tables 4 and 5*.

### Test data from SU#1

Equipment	Distance (Feet)	Direction	Detection (Yes/No)	Time to detect (MM:ss)
Mini-backhoe	100	South	Yes	AL1:1.15, AL5:1.45
Mini-backhoe	150	South	Yes	AL1: 02:00, AL5: 2.35
Mini-backhoe	150	North	Yes	AL1:1.25, AL5:1.50
Mini-backhoe	200	South	Yes	AL1:2.32, AL5:2.55
Mini-backhoe	200	North	Yes	AL1:2.30, AL4:2.58
Mini-backhoe	250	North	Yes	AL1:2.40, AL2:3.00
Pneumatic Missile	150	South	Yes	AL1:1.02, AL5:1.50
Pneumatic Missile	200	North	Yes	AL1:2.30, AL4:2.45
Pneumatic Tamper	150	South	Yes	AL1:0.25, AL5:0.50
Pneumatic Tamper	200	North	Yes	AL2:0.35, AL5:0.55

**Table 4: Advanced Design SU#1, Stony Brook, May 2012**

## Sensor #2: Testing results

Equipment	Distance (Feet)	Direction	Detection (Yes/No)	Time to detect (MM:ss)
Mini-backhoe	150	North	Yes	AL1:1.10, AL5:1.55
Mini-backhoe	200	North	Yes	AL1:1.40, AL5:3.00
Mini-backhoe	250	North	Yes	AL1:4.00
Pneumatic Missile	150	South	Yes	AL1:1.20, AL5:1.55
Pneumatic Missile	150	North	Yes	AL1:0.35, AL5:0.50
Pneumatic Missile	200	North	Yes	AL1:0.35, AL5:0.55
Tamper	150	North	Yes	AL1:0.25, AL5:0.50
Tamper	200	North	Yes	AL2:0.30, AL5:0.55

**Table 5: Advanced Design SU#2, Stony Brook, May 2012**

Compared to the target goal backhoe detection of 2 minutes at a range of 250 feet, the performance of the Advanced PG units still falls somewhat short. Detection at 250 feet was demonstrated, but the time to alarm in some cases stretched to over 4 minutes. Sub- 2 minute backhoe detection was achieved, but only out to a maximum distance of 200 feet and in some cases only 150 feet. Still, both Advanced PG systems performed considerably better than the original PG units.

## 7. CONCLUSION

The digging tests and the effort to monitor the systems for nuisance alarms has proved that geophone sensors when combined with advanced digital signal processing hardware and smart algorithms can reliably differentiate actual digging events from background clutter. The simultaneous objectives of detecting backhoe digging at 250 feet and within 2 minutes were not satisfied at either of the test sites. They were met independently however. The 250 foot goal was chosen originally to provide a 1000 foot protection zone for a system consisting of two PG SUs, or 500 feet per SU. From a technical stand point there is very little impact regarding whether a particular site requires 2, 3 or 10 PG SUs for full coverage. Each Base Station can support up to 32 SUs. Obviously there is a cost impact if each SU covers 400 feet rather than 500, but depending on the length of the actual site this may not be a consideration in many cases. The goal of detecting a backhoe digging event within two minutes was established because this would ensure an alarm was received before the gas line was reached. During the tests, backhoes generally reached a depth of approximately 18 inches after two minutes of continuous digging. While this depth is still far from a typical gas transmission or distribution line, if digging continued the backhoe could be at pipe depth within about another 5 minutes. This is a very short time window to implement a response action to effectively intercede in the digging process. The necessity for an alarm indication within two minutes then may depend on what response strategy is employed.

The primary benefit of utilizing this technology to detect unauthorized digging near buried gas lines is to reduce the risk of damages associated with third party excavations. The main features that make this product particularly well suited for short to medium pipeline lengths, is its flexibility and ease of deployment and its performance in differentiating actual digging events from background noise over and around the pipeline. The system's flexibility is owed to its modular nature. Each Sensing Unit is physically independent with integrated battery power, and wireless communication. Up to 32 units can be assigned to a single Base Station for pipeline coverage of 10,000 feet. Furthermore the Sensing Units have the flexibility to be arranged, as needed, to protect any buried asset. The installation of a SU with geophones can be completed in less than one hour and located in the vicinity of the pipeline, unlike other technologies that require installation over or directly attached to the pipeline.